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Risk assessment on falling from height based on AHP-fuzzy

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Abstract

In all the construction safety accidents, the high falling accident is the most serious construction accident of five big hurts which are threatening building workers. Risk assessment is the important means how to prevent and control falling from height accident. Based on "human - machine - environment - Management" complex system, the risk assessment index system about 4 major categories and 23 sub-categories include the quality of factors of production personnel and the production equipment factors and the environmental conditions factors and the safety management factors was established. The AHP-Fuzzy evaluation model of risk assessment of falling from height and weight sets were established based on AHP and fuzzy comprehensive evaluation method. The risk assessment example was given and the results were conformed to reality.

Keywords: risk assessment; analytic hierarchy process(AHP); fuzzy evaluation; falling from height

Nomenclature

ω	the corresponding feature vector
CI	consistency index
CR	consistency ratio
F	the final results of AHP-Fuzzy comprehensive evaluation method
Greek symbols	
λ_{max}	is the biggest characteristic root of R

1. Introduction

At present, the construction industry has become our country all the industrial sector of the most dangerous after mining industry [1]. Moreover, falling from height accident caused casualties and economic loss is the biggest in building production safety accident. Because of high incidence, its danger is the head of in construction industry "five hurts" accidents list [2]. According to *Architectural Production Safety Accidents in the First Half of Presentations in 2010* published by *Ministry of Construction of Housing and Urban-Rural, in 2010*, falling from height accident of China's total 103 up, accounting for building safety accidents of the total number of 48.13% [3]. For example, an accident had happened in coastal garden's 24-27 building project in March 26, 2010, Foshan, Guangdong, and led to two deaths. In the same year on May 9, an accident had happened because of the hospital, different newly-built project in HuanRen county, Liaoning province, and four persons were killed.

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So falling from height accident prevention and control is an important problem that should be solved in construction, the significant solution is falling risk assessment. At present many scholars had done quite a bit of research by using the fault tree method and analytic hierarchy process. Literature [4] used the fault tree analysis, the structural importance of falling from height accident basic events was determined, in the same time, calculated the key importance degree and the probability of occurrence, but, the probability of the basic events was too general. According to characteristics of falling from height accident in construction process in Literature [5], AHP was used to divide risk of falling from height into three subunits: factors of operators, objects and management. Next, risk factors were analyzed in detail and description in each subunit, and the risk assessment index system was built, its deficiency was without considering influence come from environment. Another literature [6], with falling from height accident as research object, relative importance ranking of vector of each factors which will cause the accident happened was got, then, based on the definition of brittle stimulate degrees, brittleness analysis of accident was made, and brittle sources were obtained. Deficiency is not given out safety level of this project. Due to the AHP method is a qualitative and quantitative method that processing and express men's subjective judgment with quantity forms [7], it widely applied in oil, chemical and mining fields and etc. However, its disadvantage is lack of unified and specific index quantification method during the overall evaluation when used AHP. Fortunately, the fuzzy comprehensive evaluation method can just make up it [8].

In this paper, as risk of falling from height for the research object, the index system was built by AHP-Fuzzy comprehensive evaluation method. It found that evaluation results and practical safety conditions conclusion is consistent through the engineering application. There is great significance to study the safety conditions working at height based on AHP-Fuzzy.

2. AHP-fuzzy comprehensive evaluation method

Using AHP-Fuzzy comprehensive evaluation method, the first step is decomposing problems into each composing factors, then put these factors formed recursive class times relation structure by dominating relations. Third, ensure the hierarchy of the relative importance of various factors by the fuzzy consistent judgment matrix. At last, determine general sorting of relative importance of general decision-making plan and evaluation results after composting judgment of policymakers and expert grading. The procedure is shown in Fig 1.

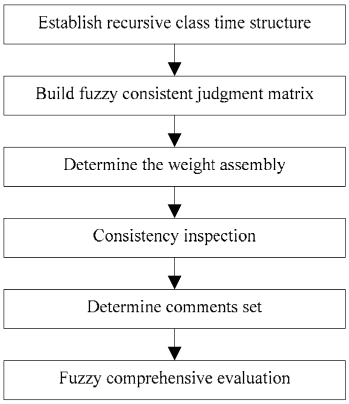

Fig. 1. Steps of AHP-Fuzzy comprehensive evaluation method.

2.1. Establish recursive class time structure

Using AHP analyze the relations of each factor in system, then establish recursive class time structure, and build the hierarchical structure model. In this situation, complex problems are made up of several elements. According to its property, these elements divided into groups, forming different layers. A certain hierarchy elements are the criterion to the next level of certain elements within a dominant, which is affected by a front layer of element the domination of the victors.

2.2. Build fuzzy consistent judgment matrix

The fuzzy consistent judgment matrix ***R*** denotes the importance degree compare between some element in the front layer and the related factor in this very layer. Assuming *C* has link with a_1, a_2, $\cdots$, a_n in the next layer, then fuzzy consistent judgment can be expressed as follow:

C	a_1	a_2	$\cdots$	a_n
a_1	r_{11}	r_{12}	$\cdots$	r_{1n}
a_2	r_{21}	r_{22}	$\cdots$	r_{2n}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
a_n	r_{n1}	r_{n2}	$\cdots$	r_{nn}

r_{ij} denotes the membership of the two elements with fuzzy relations"... than... is much more important" when a_i compares with a_j relatives to C. In order to quantitatively describe the relative importance degree for a certain criteria of any two schemes, quantity scale could be given by using 1 ~ 9 scale method (such as Table 1).

Using the upper number scale, the fuzzy judgment matrix ***R*** was obtained as follow:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{na} & r_{n2} & \cdots & r_{nn} \end{bmatrix}$$

Table 1. Meanings of 1 –9 scale

scale	meanings of scale
1	says two factors compared with same importance
3	says two factors compared, some factor than another factor is slightly important
5	says two factors compared, some factor than another factor is obvious important
7	says two factors compared, some factor than another factor is strong important
9	says two factors compared, some factor than another factor is extreme important
2,4,6,8	says middle value of above
reciprocal	b_{ij} denotes *i* compares with *j,* so b_{ji}=1/b_{ij}

2.3. Determining weight set

The ultimate purpose of analytic hierarchy process is attributed system analysis into a problem how to identify relative weight that the bottom relative to the summit.

If we supposed the weight value of elements a_1, a_2, $\cdots$, a_n respectively is ω_1, ω_2, $\cdots$, ω_n, relative weight can be written as vector format: $\omega = (\omega_1 \quad \omega_2 \quad \cdots \quad \omega_n)^T$. At this step, it transforms how to use characteristic root method calculate the weight and solve characteristic root of fuzzy judgment matrix ***R***.

$$R\omega = \lambda_{\max}\omega \tag{1}$$

Where, λ_{max} is the biggest characteristic root of ***R***, ω is the corresponding feature vector and it could used as weight vectors after normalization. In other words, it is the relative importance ranking weights.

It must validate the consistency while are determining the weight assembly.

At first, should calculate consistency index $CI = \frac{(\lambda_{\max} - n)}{(n-1)}$. Second, find corresponding average random consistency index. The 3~9 order average random consistency indexes are given in Table 2.

Table 2. Average random consistency index

Order number	3	4	5	6	7	8	9
RI	0.52	0.89	1.12	1.24	1.32	1.41	1.45

Finally, calculate and inspect consistency ratio $CR = \frac{CI}{RI}$. If $CR < 0.1$, the result is acceptable, or it's need to modify the fuzzy judgment matrix.

2.4. Fuzzy comprehensive evaluation

Comments set contain all kinds of evaluation results that evaluators may make. Let $v = (v_{1,} v_2, \cdots, v_n)$ respectively denotes low to high levels of comments. Then give assignments for comments set, the membership $S = (1, 2, \cdots, n)$ of various comments will be obtained.

At 3 level of hierarchical structure, firstly evaluate the evaluation factors of secondary indexes, the result is comprehensive evaluation set B_i.

$$B_i = A_i \circ R_i \tag{2}$$

where, symbols " $\circ$ " means relationship synthesis operator. In this work, it should have overall consideration various influential factors, use the weighted average type operator $M = (\circ, \oplus)$, and then evaluate every factor of U in one class index, the result as follow:

$$B = A \circ R = A \circ (R_1, R_2, \cdots R_m) \tag{3}$$

At last, give scores for every comprehensive evaluation results.

$$F = B \circ S^T \tag{4}$$

where, F is the final results of AHP-Fuzzy comprehensive evaluation method.

3. Evaluation Index System

Working at height production system, which is dynamic, random and fuzzy and complicated. In order to scientifically evaluate the risk of falling from height, must ensure the parameter indexes that can precisely reflect the actual conditions of production system, then establish a scientific and reasonable evaluation index system. If the evaluation indexes are too much, it perhaps increases the complexity of evaluation index structure and the difficulty of evaluation, even the main key factors will be covered. Meanwhile, if the evaluation indexes are too little, although the evaluation process becomes simple, the objective evaluation object situation is difficult to be reflected. Therefore, to guarantee the comprehensive evaluation of comprehensiveness and credibility, index system should seize main factors and be able to fully reflect the comprehensive situation of evaluated objects. In this way, not only the directly effect but also the indirectly effect will be clear at a glance. And it could reach in technically feasible, economic and reasonable goals.

In order to research the falling accident harm, look for the weak links of the working at height system and the technical improvement for safety, falling risk evaluation index overall structure was established, through analyzing "man-machine-environment-management" system, the secondary indexes was obtained after further specifying factors of production personnel quality, the production equipment, production environment and safety management. In order to satisfy the needed information of evaluation model and the data processing requirements, all the indexes were described quantitatively and qualitatively. Based on the analytic hierarchy process (AHP), risk falling from height evaluation index system was divided into target layer, criterion layer (the first class index) and index layer (secondary indexes) as Fig 2 shows.

4. Evaluation example

In this paper, taking a certain project working at height engineering for example, comprehensive evaluate the falling risk by using the model mentioned in the front.

Factors of risk of falling from height index shows as Fig 2.

$$U = (U_1, U_2, U_3, U_4),\ U_1 = (U_{11}, U_{12}, U_{13}, U_{14}, U_{15}, U_{16}, U_{17}),\ U_2 = (U_{21}, U_{22}, U_{23}, U_{24}, U_{25}),$$
$$U_3 = (U_{31}, U_{32}, U_{33}, U_{34}, U_{35}),\ U_4 = (U_{41}, U_{42}, U_{43}, U_{44}, U_{45}, U_{46})$$

Establishing indexes of all levels of binary comparison matrix, the maximum eigenvalue of each matrix respectively and its corresponding normalized vector is obtained through Matlab programming, and then does consistency test, the weight set is listed in Table 3. It found that each random consistency ratio CR random consistency ratio is less than 0.1.

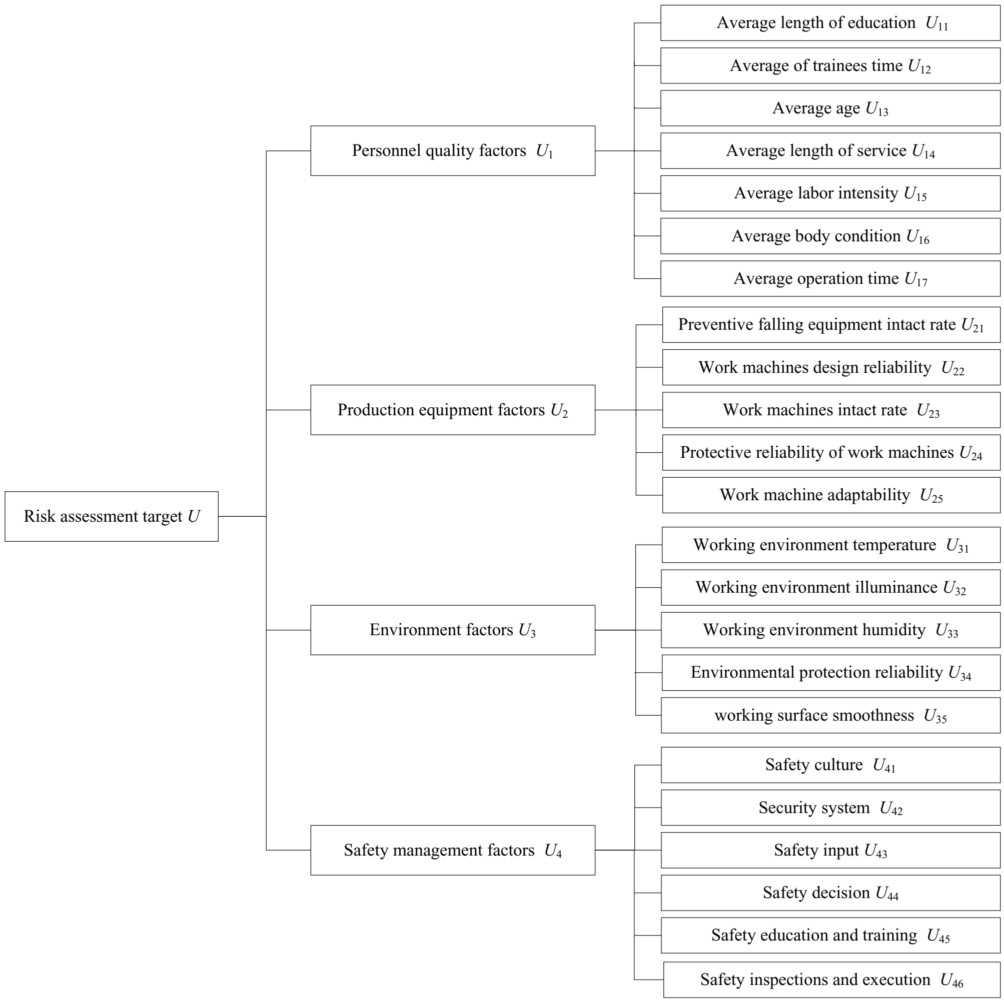

Fig. 2. AHP-Fuzzy comprehensive evaluation index system.

Table 3. Weight set and consistency test results

Weight set	λ_{max}	i, j	RI	CI	CR
A =(0.10,0.21,0.26,0.43)	4.12	4	0.90	0.04	0.04
A_1 =(0.08,0.28,0.26,0.08,0.09,0.10,0.11)	7.64	7	1.28	0.14	0.08
A_2 =(0.26,0.26,0.11,0.27,0.10)	5.13	5	1.12	0.03	0.03
A_3 =(0.11,0.18,0.37,0.21,0.13)	5.06	5	1.12	0.01	0.01
A_4 =(0.15,0.31,0.30,0.09,0.09,0.06)	6.31	6	1.24	0.06	0.05

Divide risk of falling from height into 5 grades: unsafe, relatively unsafe, generally safe, relatively safe, safe. Its membership expression is $S = (1,2,3,4,5)$.

4.1. Evaluation sample matrix

Now invite twenty related personnel who are experienced do risk of falling from height evaluation for the project, among them five experts, five security officers, five construction group captains, five worker representatives. The sample matrixes were built as follows, for example, the first column $(0,1,4,12,3)$ in $\boldsymbol{R}_1$, it means, for the factor of average length of education

U_{11}, there three people judged for safety, twelve people judged for relatively safe, four people judged for general safety, one person judged for relatively unsafe, no one judged for unsafe.

$$R_1 = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 1 & 2 & 0 & 3 & 1 \\ 4 & 1 & 2 & 3 & 1 & 5 & 2 \\ 12 & 13 & 16 & 5 & 13 & 5 & 12 \\ 3 & 5 & 1 & 10 & 6 & 7 & 4 \end{bmatrix}^T \quad R_2 = \begin{bmatrix} 0 & 1 & 2 & 0 & 1 \\ 2 & 1 & 0 & 4 & 3 \\ 4 & 2 & 0 & 1 & 1 \\ 11 & 12 & 13 & 7 & 10 \\ 3 & 4 & 5 & 8 & 5 \end{bmatrix}^T$$

$$R_3 = \begin{bmatrix} 2 & 1 & 0 & 1 & 1 \\ 6 & 2 & 3 & 0 & 2 \\ 5 & 1 & 2 & 7 & 2 \\ 7 & 10 & 8 & 6 & 11 \\ 0 & 6 & 7 & 6 & 4 \end{bmatrix}^T \quad R_4 = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 & 0 \\ 2 & 3 & 3 & 2 & 1 & 2 \\ 1 & 7 & 2 & 2 & 1 & 4 \\ 9 & 6 & 10 & 11 & 12 & 11 \\ 6 & 4 & 4 & 6 & 5 & 3 \end{bmatrix}^T$$

4.2. Fuzzy comprehensive evaluation

After respectively normalizing $\boldsymbol{R}_1$, $\boldsymbol{R}_2$, $\boldsymbol{R}_3$, $\boldsymbol{R}_4$, the evaluation result will be got. According to Formula (2), it could calculate out B_1:

$$B_1 = A_1 \circ R_1 = (0.0195, 0.0455, 0.1085, 0.6075, 0.2190)$$

The results show that, in whole evaluation members there 21.9% of the people consider that the personnel quality factors is safe, 60.75% consider that it's relatively safe, 10.85% consider that it's generally safe, 4.55% consider that it's relatively unsafe, 1.95% consider that it's unsafe. Give scores for the corresponding evaluation grades, and then F_1 is obtained according to Formula (4).

$$F_1 = B_1 \circ S^T = (0.0195, 0.0455, 0.1085, 0.6075, 0.2190) \circ (1,2,3,4,5)^T = 3.961$$

It found that "3.961" is close to "4", the personnel quality factors index of this company could be regarded as "relatively safe". Ordinal analogy computing, comprehensive evaluation set B available could be got.

$$B = A \circ R = (0.10, 0.21, 0.26, 0.43) \circ \begin{bmatrix} 0.0195 & 0.0455 & 0.1085 & 0.6075 & 0.2190 \\ 0.0290 & 0.1080 & 0.0965 & 0.5150 & 0.2510 \\ 0.0370 & 0.1195 & 0.1600 & 0.4110 & 0.2725 \\ 0.0270 & 0.1260 & 0.1715 & 0.4470 & 0.2255 \end{bmatrix}$$

$$= (0.0293, 0.1125, 0.1465, 0.4680, 0.2424)$$

Its score is: $F = B \circ S^T = (0.0293, 0.1125, 0.1465, 0.4680, 0.2424) \circ (1, 2, 3, 4, 5)^T = 3.7776$

According the risk assessment model and evaluating steps, the result is got through programming calculation in the basis of Matlab, and the comprehensive evaluation value is 3.7776. Compared with the evaluation grades, "3.7773" is very close to "4" (relatively safe). Therefore, the final comprehensive evaluation result of this project is "relatively safe".

Meanwhile, the safety self-check report of this company and monthly safety inspection report written by supervising firm shows that the reality risk is "relatively safe". It means that the calculation result is accord with actual situation. Thus, the AHP - Fuzzy comprehensive evaluation model is feasible.

5. **Conclusions**

Falling from height accident prevention and control is an important problem that should be solved in construction, risk assessment is the important means how to prevent and control it. Its purpose is to improve the working at height essence safety degree and the level of safety management, prevent and control of accidents. This paper establish the risk of falling from height Fuzzy-AHP comprehensive evaluation index system, acquires the following conclusion combining evaluation example verification.

(1) Based on system safety engineering theory, influence factors of falling from height are analyzed detailed, and the evaluation index system is put forward.

(2) The structure and weights of target strata, criterion layer and index layer are determined by application of fuzzy comprehensive evaluation model of AHP.

(3) Evaluation example result accord with the actual situation, it is shown that the AHP-Fuzzy comprehensive evaluation method and the evaluation index system are reliable and practical.

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References

[1] ZHANG Shilian, DONG Yong, PAN Cheng-shi. Construction Safety Management. Beijing: China Architecture and building Press, 2005.
[2] Ma Bin, CHEN Lidao, JIANG Min. Study on Falling Accidents in Construction Industry. China Safety Science Journal 2004, 14(9): 108-112.
[3] JIANG Weixin, QIU Baoxing, CHEN Dawei, et al. National Construction Safety Situation Analysis Report. Ministry of Housing and Urban-Rural Development of the People`s Republic of China. http://www.mohurd.gov.cn/zcfg/jswj/gczl/. 2010.
[4] ZHANG Mingxuan, ZHU Yuejiao, ZHAI Yu-jie. et al. Research on fault tree analysis method for fell down accident from high building in construction. Coal Engineering 2008(2): 112-114.
[5] XIAO Huade, HE Guishan. Research on safety assessment method for high falling. Safety 2009, (7): 8-11.
[6] ZHAO Jinna; GUO Jinping; HOU Dongsheng, et al. Analysis of brittleness of falling accident based on analytic hierarchy process, Journal of Safety Science and Technology 2009, 5(5): 204-208.
[7] WANG Lian-fen, XU Shu-bo. Analytic Hierarchy Process. Beijing: China Renmin University Press, 1990.
[8] ZHANG Ji-jun. Fuzzy Analytical Hierarchy Process. Fuzzy Systems and Mathematics 2000, 14(2): 80-88.
[9] HU Yong-hong, HE Si-hui. Fuzzy Comprehensive Evaluation Method. Beijing: Science Press 2000.
[10] HUANG Guo-yao, XU Jiang, CHE Ren, et al. Investigation and analysis on falling accidents of construction area in Chongqing. Journal of Safety Science and Technology 2007, 3(1): 54-57.